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# NONLINEAR DECAY OF ELECTROSTATIC PUMP WAVE IN FERROELECTRIC MATERIALS WITH SDDS

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## ABSTRACT

A comprehensive systematic analysis is made of the nonlinear decay process in ferroelectric material like BaTiO3 in semiconducting plasma. The dispersion relation is obtained by using a hydrodynamic model o fin homogeneous, ferroelectric, one-component (electron or proton) semiconducting plasma. The threshold value of pump electric field and the growth rate of unstable mode well above the threshold are discussed. This analysis is applied to a specific semiconductor, BaTiO3at 77K with strain dependent dielectric constant (SDDC). The laser wave intensities used are in the range of 109 to1012 Wm-2 which is assumed to be less damage threshold. The growth rate which is being found in this study is 1012 s-1. In non-liner wave propagation by the analyses of interaction depending on a particular physical situation is of great importance. It is a fact that the study of matter wave interaction provides a tremendous insight that is very much helpful to analyses the fundamental properties and characteristics of the medium. In this paper we concentrate on nonlinear interactions in ferroelectric semiconducting crystal. It is perceived that a significantly high growth rate is obtained in ferroelectric materials with strain dependent dielectric constant (SDDC). The ferroelectric crystal with SDDC thus feasibly offers an area of assurances to pursuit's nonlinear interactions and one expects the experimental studies on nonlinear interactions to open a potential tool for energy conversion and solid state diagnostics in crystal with strain dependent dielectric constants.

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## INTRODUCTION

The low loss or loss less nonlinear energy storage mechanism couple a number of normal modes at different frequency in a generalized dynamic system represents the nonlinear interactions. The interaction or coupling of a pair of modes of one reactive, one active leads to instabilities. Nonlinear instabilities can be thrilled by feeding energy into a system. This investigation of interaction depending on a particular physical circumstances is of great significance. As a consequence of nonlinear interactions between matter and wave, there arises observable fact such as Parametric, Modulation and stimulated scatterings to name a few. The most fundamental interaction is the Parametric Interaction. The understanding of these phenomena have led to their successful application in the field like laser technology, laser spectroscopy, optical communication, photo physics, Photochemistry, Materials Processing etc. It is well known fact that the study of matter wave interaction provides a tremendous insight that is helpful in analyzing the basic properties of the medium Ghosh, S., and Sontakke, K.,[1]. There exist a number of non-linear interactions which can be classified as parametric excitations of coupled modes. By parametric excitation of coupled modes one means the phenomenon in which the energy of external pump wave field is transferred to the system under consideration by a resonant mechanism that takes place when the field amplitude is large enough to cause the vibration (with the external-field frequency) of certain physical parameters of the system. Parametric excitations describing the decay of a large amplitude electromagnetic pump wave in unmagnetized gaseous plasmas are well studied by Nishikawa, K., Drake, C. S., at el.,[2-4]. The theory of parametric excitations driven by a finite wave number general pump wave has been developed by Sanuki and Schmidt[5] for the case where the pump wave and the decay products can be electromagnetic as well as electrostatic, Tripathi et al.,[6] generalized the investigation of Ott[7] to consider other decay channels involving various types of electrostatic waves. The possibility of a new decay channel consisting of two electromagnetic waves has been pointed out Shukla and Mamedow[8]. Many of the non-linear processes occurring in gaseous plasmas may also occur in other media and recently attention has been drawn to study parametric interactions in solid state plasmas. The parametric decay of an electromagnetic pump-wave into electron plasma and acoustic waves Ghosh, S., and Dixit, S.,[9] and acoustohelucon wave[10] in magneto active piezoelectric semiconductor plasmas have been studied by Ghosah and Dixit[11]. Also the parametric decay of circularly polarized laser and Salimullah et al.,[12][13] shown the possibility of conversion of an electrostatic pump-wave into plane polarized and circularly polarized piezoelectric semiconductor plasma in the presence of the carrier density gradient. The fundamental difference between the plasma in solid and the gaseous plasma is that in solids the motion of mobile charges (charge carriers) of the plasma under the action of external forces occurs not as that of free particles but first under the condition of strong interaction with the field of atom that from the lattice and second in the presence of intense friction resulting from numerous collision with defect and vibration of crystalline lattice Artsimovich, L. A. et. al.,[14]. The highlights the parametric instabilities of laser beams in material with strain dependent dielectric constant Ghosh S., Dixit S.,[15]. In the above referred paper it is found that anomalously large values of growth can be obtained for materials with large values of the dielectric constant which otherwise cannot be achieved with piezoelectric interaction. They have done the estimations for BaTiO$_3$ crystal irradiated with a pulsed 10.6 $\mu m$ CO$_2$ laser. The investigation of Laser, the sources of high-intensity radiation in the micro-wave and infrared optical spectra range, has caused a considerable increase of both theoretical and experimental investigation of nonlinear interaction of high intensity electromagnetic field with matter.

### 1.1 Theoretical Formulation

We have painstaking one component like electron in inhomogeneous piezoelectric semiconducting plasma immeasurable extent subjected to an electrostatic pump wave of the form $E_0 \exp[i(\Omega_0 t - k_0 z)]$ along z-axis.The basic equations involved in the analysis are the both order and first -order momentum transfer and the continuity equations, Maxwell's equations and the equation of motioand the equation of Elasticity theory describing the motion of lattice in SDDC crystal become

$$\varrho \frac{\partial^2 u}{\partial t^2} = C\frac{\partial^2 u}{\partial z^2} - \varepsilon_0 g E_0 \frac{\partial E}{\partial z}, \tag{1}$$

$$D_1 = \varepsilon_0 E + \varepsilon_0 g s E, \tag{2}$$

$$\nabla \times \nabla \times E_1 = -\mu_0 \frac{\partial J_1}{\partial t} = \frac{1}{C_L^2}\frac{\partial^2 E_1}{\partial t^2} - \mu_0 \frac{\partial^2(\varepsilon_0 g s E)}{\partial t^2}\frac{\partial u}{\partial z} \tag{3}$$

$$J_1 = e(n_0 v_1 + n_1 v_0). \tag{4}$$

$$\nabla . E_1 = \frac{e n_1}{\varepsilon_0} - \frac{\varepsilon_0 g E_0}{\varepsilon_0}\nabla^2, \tag{5}$$

$$n_{1s} = \frac{\varepsilon_0}{e}\left[\frac{\Omega^2 - k^2 v_s^2 - \frac{\varepsilon_0^2 g^2 E^2}{\varrho \varepsilon_0} k^2}{\Omega^2 - k^2 v_s^2}\right]\nabla . E_1 , \tag{6}$$

and

$$n_{1f} = -\left[\frac{2ik\delta\overline{E}}{\Omega_0(\nu^2 + \delta^2)}\right] n_{1f} \tag{7}$$

In which $\Omega_{cz} = \Omega_c \sin\theta$ and $\Omega_c^2 = \Omega_{cx}^2 + \Omega_{cz}^2$. similarly, the components of $v_1(= v_{1f} + v_{1s})$ are derived from eq. and given by

$$v_{1x} = \frac{e}{m\left\{(\overline{\Omega} - i\nu)^2 - \Omega_c^2\right\}}\left[-i\frac{\left\{(\overline{\Omega} - i\nu)^2 - \Omega_{cx}^2\right\}}{(\overline{\Omega} + i\nu)} E_{1x} - \Omega_{cz} E_{1y} + \frac{i\Omega_{cx}\Omega_{cz} b}{(\overline{\Omega} + i\nu)} E_{1z} + \frac{\Omega_{cx}\Omega_{cz}}{(\overline{\Omega} + i\nu)} . \frac{k^3 v_{th}^2}{\Omega_p^2}\frac{\varepsilon_0 g E_0}{\varepsilon_0} u\right] v_{1y} = \frac{e}{m\left\{(\overline{\Omega} - i\nu)^2 - \Omega_c^2\right\}} . \left[\Omega_{cz} E_{1x} - i(\overline{\Omega} + i\nu) E_{1y} - \Omega_{cx} b E_{1z} + i\Omega_{cx} . \frac{k^3 v_{th}^2}{\Omega_p^2}\frac{\varepsilon_0 g E_0}{\varepsilon_0} u\right]$$

,

and

$$v_{1z} = \frac{-e}{m\left\{(\overline{\Omega} - i\nu)^2 - \Omega_c^2\right\}} . \left[\frac{-i\Omega_{cz}\Omega_{cx}}{(\overline{\Omega} + i\nu)} E_{1x} - \Omega_{cx} E_{1y} + \frac{ib\left\{(\overline{\Omega} - i\nu)^2 - \Omega_{cz}^2\right\}}{(\overline{\Omega} + i\nu)} E_{1z} - \frac{i\left\{(\overline{\Omega} - i\nu)^2 - \Omega_{cz}^2\right\}}{(\overline{\Omega} + i\nu)}\frac{k^3 v_{th}^2}{\Omega_p^2}\frac{\varepsilon_0 g E_0}{\varepsilon_0} u\right],$$

$$u = \frac{J_z}{k\Omega\varepsilon_0 g E_0} - \frac{i}{k\Omega\varepsilon_0 E_0}\left[\frac{k_1^2}{\Omega_1\mu_0} - \varepsilon_0\Omega_1\right] E_{1x}$$

$$J_{1x} = \frac{\varepsilon_0\Omega_p^2}{\left\{(\overline{\Omega} - i\nu)^2 - \Omega_c^2\right\}} . \left[\frac{-i\left\{(\overline{\Omega} - i\nu)^2 - \Omega_{cx}^2\right\}}{(\overline{\Omega} - i\nu)} E_{1x} - \Omega_{cz} E_{1y} + \frac{i\Omega_{cx}\Omega_{cz} b}{(\overline{\Omega} - i\nu)} E_{1z}\right], \tag{8}$$

$$J_{1y} = \frac{-i\varepsilon_0\Omega_p^2}{\left\{\left(\overline{\Omega}-i\nu\right)^2-\Omega_c^2\right\}}.\left[i\Omega_{cz}E_{1x} + \left(\overline{\Omega}-i\nu\right)E_{1y} - i\Omega_{cx}bE_{1z}\right], \tag{9}$$

and

$$J_{1z} = \frac{-\varepsilon_0\Omega_p^2}{(1-Q)\left\{\left(\overline{\Omega}-i\nu\right)^2-\Omega_c^2\right\}}.\left[\frac{-i\Omega_{cx}\Omega_{cz}}{\left(\overline{\Omega}-i\nu\right)}E_{1x} - \Omega_{cx}E_{1y} + \frac{i\left\{b\left(\overline{\Omega}-i\nu\right)^2-\Omega_{cz}^2\right\}}{\left(\overline{\Omega}+i\nu\right)}E_{1z} + \frac{Q\left(k_1^2C_L^2-\Omega_1^2\right)\left\{\left(\overline{\Omega}-i\nu\right)^2-\Omega_{cz}^2\right\}}{\Omega_1\Omega_p^2}E_{1z}\right], \tag{10}$$

Where we have assumed that

$E_{1x} \gg \frac{\Omega_{cx}\Omega_{cz}}{\left(\overline{\Omega}-i\nu\right)}\frac{k^3\upsilon_{th}^2}{\Omega_p^2}\frac{\varepsilon_0 gE_0}{\varepsilon_0}u, E_{1y} \gg \Omega_{cx}\frac{k^3\upsilon_{th}^2}{\Omega_p^2}\frac{\varepsilon_0 gE_0}{\varepsilon_0}u, E_{1z} \gg \frac{\left\{\left(\overline{\Omega}-i\nu\right)^2-\Omega_{cz}^2\right\}}{\left(\overline{\Omega}+i\nu\right)}\frac{k^3\upsilon_{th}^2}{\Omega_p^2}\frac{\varepsilon_0 gE_0}{\varepsilon_0}u,$ And

$$Q = \frac{\upsilon_{0z}\varrho\varepsilon_0}{k\Omega\varepsilon_0^2g^2E_0^2}\left\{\Omega^2 - k^2\upsilon_s^2 - \frac{\varepsilon_0^2g^2E^2k^2}{\varrho\varepsilon_0}\right\}.\left\{1 - \frac{2i\delta k\overline{E}}{\Omega_0(\nu^2+\delta^2)}\right\}. \tag{11}$$

From (8) the wave equation for the ferromagnetically excited waves with frequency $\Omega_1(\approx \Omega_0 as\ \Omega \ll \Omega_0)$ and wave number $k_1(\approx k)$ is obtained by presumptuous the space and time dependence as $exp[i(\Omega_1 t - k_1 z)],$

$\hat{\imath}k_1^2E_{1x} + \hat{\jmath}k_1^2E_{1y} + i\Omega_1\mu_0J_1 - \frac{\Omega_1^2}{C_L^2}E_1 = -\mu_0\frac{\partial^2}{\partial t^2}\left(\varepsilon_0 gE_0\frac{\partial u}{\partial z}\right)$ Obtains:

$$a_{33} = \frac{\Omega_1\Omega_p^2b\left\{\left(\overline{\Omega}-i\nu\right)^2-\Omega_{cz}^2\right\}}{(1-Q)\left(\overline{\Omega}-i\nu\right)\left\{\left(\overline{\Omega}-i\nu\right)^2-\Omega_c^2\right\}} + \frac{Q\left(k_1^2C_L^2-\Omega_1^2\right)}{(1-Q)} - \Omega_1^2\left[1 - \frac{\mu_0k_1^2C_L^2\varepsilon_0^2g^2E_0^2}{\left(\Omega^2-k^2\upsilon_s^2\right)},\right] \tag{12}$$

Eq.(12)shows that the three modes represented by $a_{11} = 0$, $a_{22} = 0$ and $a_{33} = 0$ are coupled to each other via the finite magneto static field $B_0$.

$$(\Omega^2 - k^2\upsilon_s^2)\left[-\Omega_1\left(\overline{\Omega}-i\nu\right) + \Omega_R^2\right] = -\Omega_1 D\left(\overline{\Omega}-i\nu\right) \tag{13}$$

In which $D = \frac{k^2C_L^2\mu_0\varepsilon_0^2g^2E_0^2}{\varrho}$,

$$(E_{0th}) = \frac{m}{e\Omega_c}[(\nu^2 + \Omega_c^2) - \Omega_0^2]\left(\frac{\upsilon_s\Omega_0}{k}\right)^{\frac{1}{2}} \tag{14}$$

$$|\Omega_i|_\nu = \left(\frac{e}{m}\right)^2\frac{\Omega_c^2\Omega_1k^2C_L^2\mu_0\varepsilon_0^2g^2E_0^2}{2\varrho\upsilon_s^2(\Omega_R^2 - \Omega_1\Omega_r)\{(\nu^2 + \Omega_c^2) - \Omega_0^2\}^2}E_0^2$$

$$(\Omega^2 - k^2\upsilon_s^2)[\Omega_R^2\{(\Omega_r^2 - \Omega_c^2)^2 - 2\Omega_{cx}^2\Omega_{cz}^2\} - \Omega_1(1-Q)(\Omega_r - i\nu)(\Omega_r^2 - \Omega_c^2)^2] = -(1-Q)D\Omega_1(\Omega_r - i\nu)(\Omega_r^2 - \Omega_c^2)^2 \tag{15}$$

$$(\Omega_i)_G = [(1-Q)\Omega_1 D\nu(\Omega_r - i\nu)(\Omega_r^2 - \Omega_c^2)^2].\left[2\Omega_r[\Omega_R^2\{(\Omega_r^2 - \Omega_c^2)^2 - 2\Omega_{cx}^2\Omega_{cz}^2\} - \Omega_1\Omega_r(\Omega_r^2 - \Omega_c^2)^2]\right]^{-1} \tag{16}$$

The growth rate well above the threshold is obtained as

$$|\Omega_i|_G = \left(\frac{e}{m}\right)^2[\Omega_1\Omega_{cx}^2k^2C_L^2\mu_0\varepsilon_0^2g^2E_0^2(\Omega_r^2 - \Omega_c^2)E_0^2].\left[2\upsilon_s^2\varrho\{(\Omega_c^2 + \nu^2) - \Omega_0^2\}^2[\Omega_R^2\{(\Omega_r^2 - \Omega_c^2)^2 - 2\Omega_{cx}^2\Omega_{cz}^2\} - \Omega_1\Omega_r(\Omega_r^2 - \Omega_c^2)^2]\right]^{-1} \tag{17}$$

In obtaining eq. (16) we have assumed that $Q > 1$,

$$\Omega_R^2[(\Omega_r^2 - \Omega_c^2)^2 - 2\Omega_{cx}^2\Omega_{cz}^2] > \Omega_1\Omega_r(\Omega_r^2 - \Omega_c^2)^2$$

This gives the threshold value of the carrier concentration as-

$$n_{0th} = \frac{m\varepsilon_0\varepsilon_L}{e^2}\left[\left[\frac{\Omega_1\Omega_r}{1-\left\{2\Omega_{cx}^2\Omega_{cz}^2/(\Omega_r^2-\Omega_c^2)^2\right\}}\right]-k^2v_{th}^2\right] \tag{18}$$

## RESULT AND DISCUSSION

We have pragmatic the above analysis to the case of BaTiO$_3$ at 77K with the following constants: g = $\frac{\varepsilon_0}{3}$, m = 0.014m$_0$, $\varepsilon_L$= 17.8, ν = 3.5×10$^{17}$s$^{-1}$, $\varepsilon_0 g E_0 = 0.054m^{-2}$, ϱ = 5.8×10$^3$kgm$^{-3}$, n$_0$ =2.507×10$^{20}$m$^{-3}$, and the crystal is assumed to be irradiated with a large amplitude electron plasma wave of frequency Ω$_0$ = 1.78×10$^{15}$s$^{-1}$ and k$_0$ = 4×10$^7$m$^{-1}$. Using these data we get $(E_{0th})_{B_0=0} \approx 1.8146 \times 10^6 Vm^{-1}$ and the growth rate $|\Omega_i|_{B_0=0}$ is equal to 8.0256×10$^8$ s$^{-1}$ at E$_0$ = 10$^7$Vm$^{-1}$. The electrostatic pump wave with such afield strength to produce the phenomenon of ferroelectric excitation of an electromagnetic wave may be generated by injecting fast electron sheet beams into plasmas where the electron plasma wave is found to be excited nearly perpendicularly to the expanse beam.

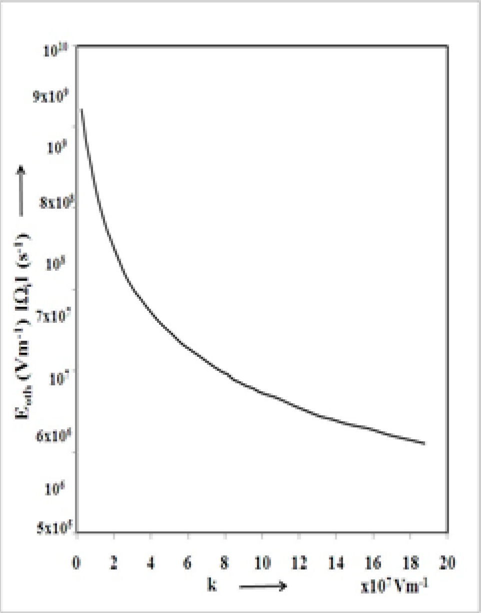

*Fig. 1 Represents the variation of E$_{0th}$ on k increase the value of k, enhances the field growth rate and reduces the threshold electric field amplitude at θ=45°, k=2x10$^7$ m$^{-1}$ E$_0$ = 10$^7$ Vm$^{-1}$.*

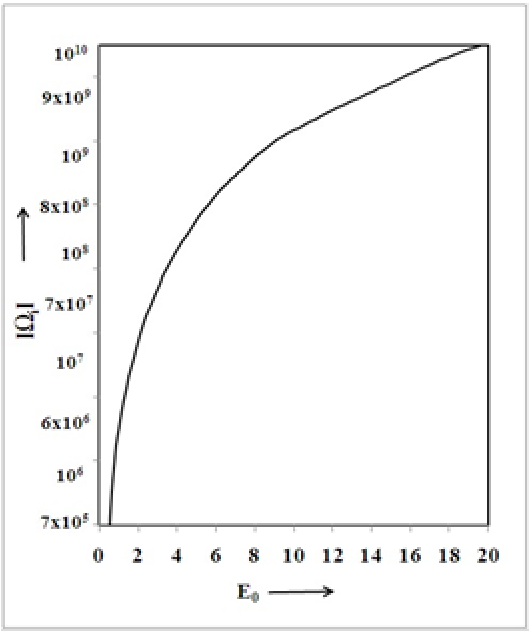

*Fig.2 Dependence of growth rate |Ω$_i$| of the unstable mode on the pump electric amplitude E$_0$ at θ = 45°, Ω$_c$ = 15x 10$^{15}$ s$^{-1}$ k = 2x10$^7$ m$^{-1}$*

The results are plotted in Fig. 1 to 2. Fig.1 deals with the relation between E$_{0th}$ and *k* and it can be noticed from Fig. 1 Represents the variation of E$_{0th}$ on k increase the value of k, enhances the growth rate and reduces the threshold electric field amplitude. However, we have to restrict ourselves upto $\Omega_c = 1.5 \times 10^{14}s^{-1}$ to satisfy the assumption $(\Omega_0 \gtrsim \Omega_c$. Fig. 2 shows the variation of the growth rate $|\Omega_i|$ with electric field amplitude of the pump $E_0$. The growth–rate increases with the increase in the field amplitude B$_0$. However, we have limited ourselves to a high value of E$_0$ of the order of 1.5×10$^7$ Vm$^{-1}$, as there is a possibility of damage to the crystal if a very high-intensity beam with E$_0$> 1.5×10$^7$ Vm$^{-1}$ is applied.

## CONCLUSION

It is found that anomalously large values of growth can be obtained for materials with large values of the dielectric constant which otherwise cannot be achieved with nonlinear interactions. We have done the estimations for $BaTiO_3$ crystal irradiated with a pulsed 10.6 $\mu m$ $CO_2$ laser. Thus our analysis can be employed effectively in the investigation of parametric decay of electrostatic waves in high dielectrics with electron concentrations such that the electron plasma frequencies are nearly equal to the pump frequency. Hence from the above referred work we concluded that parametric interaction in ferroelectric materials with strain dependent dielectric constant of solid state plasma is an efficient tool for the fabrication of optoelectronic devices such as optical parametric oscillators, optical resonators etc.

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## REFERENCES

[1] Ghosh, S., Sontakke, k., I. J. S. R. P., 3 [2013] 2,

[2] Nishikawa, K, J. Phy. Soc. Japan 24 [1986], 916.

[3] Nishikawa, K, J. Phy. Soc. Japan 24 [1986], 1152.

[4] Drake, J. F., Kaw, P.K., Lee, Y. C., Schmidt, G., Liu, C. S., and Rosenbluth, M.N., Phys. Fluids 17 [1974], 778.

[5] Sanuki, H. and Schmidt, G., J. Phys. Soc. Japan 42 [1977], 664.

[6] Tripathi, V. K., Grebogi, C., and Liu, C. S., Preprint No. 701 Pool, University of Maryland 1977.

[7] Ott, E., Phys. Fluids 18 [1975], 566.

[8] Shukla, P. K. and Mamedow, M.A., J. Plsama Phys. 19 [1978], 87.

[9] Ghosh, S., and Dixit, S., Acustica56 [1984], 154.

[10] Ghosh S., and Dixit S., Phys. Stat. Sol. (b) 130 [1985] 260.

[11] Ghosh S., and Dixit S., Int. J. Acustica56 [1984].

[12] Salimullah, M. and Singh, T., J. Phys. Chem. Solids, 43[1982], 1087.

[13] Salimullah, M. and Alam, M. N., J. Appl. Phys. 53 [1982], 4534.

[14] Artsimovich, L. A., Elementary Plasma Physics, Blaisdell, New York, [1965].

[15] Dixit S., Ghosh S., J. of Ultrasonics Y11 [1986], 86